Advanced Modeling of Anisotropic Stochastics in EUV Resist

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Motivation/ Objectives

Motivation
- Resist stochastics limit the quality of EUVL printed circuits
- As feature sizes become smaller, the relative importance of stochastics in resist becomes higher
- In DUV CAR resist, anisotropic deprotection phenomena is significant (Zuniga, SPIE 1995)
- Future of EUVL depends on improvement of resist as well as EUV optics

Objectives
- Develop fast, stochastic resist models that describe observed phenomena
- Measure resist PEB acid/ quencher diffusion characteristics
- Explore the effect of substrate chemistry on PEB

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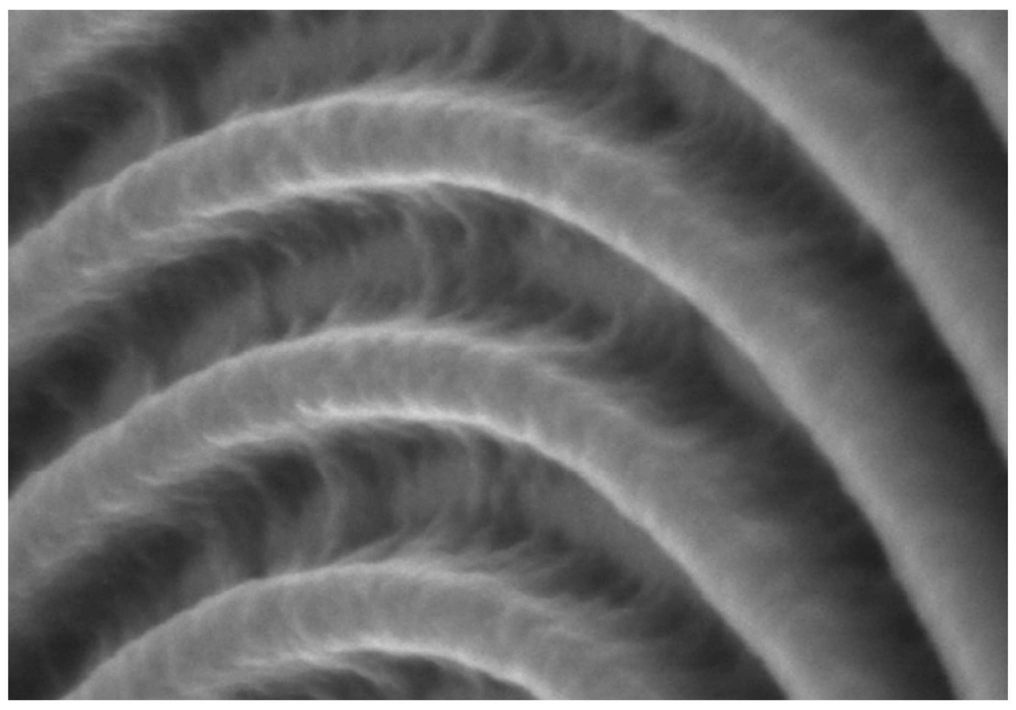
Stochastics Play a Significant Role



-Simi George, SPIE 2010

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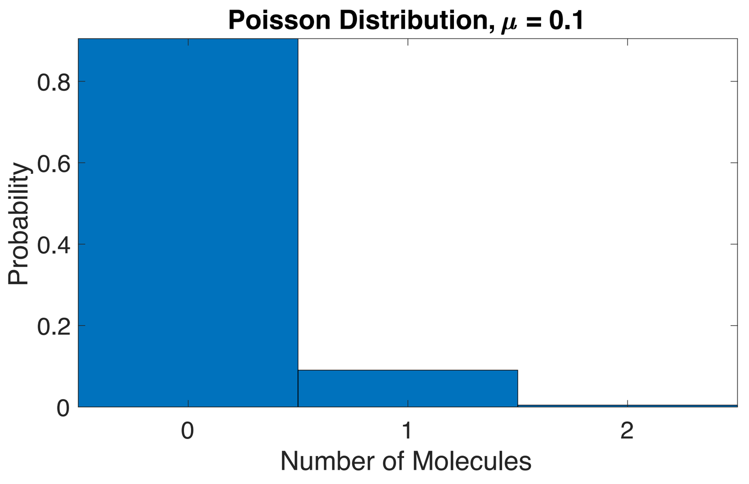
Basic Stochastics

- Chemical concentrations & absorbed photons are randomly distributed
- Poisson: $P(X=n) = e^{-\mu}\frac{\mu^n}{n!}$ with μ as mean
- Result: Inhomogeneous initial acid/ quencher concentration
- e.g. PAG concentration of 0.1 molecules/nm^3 @ 1 nm^3 voxel

Most voxels contain no PAG



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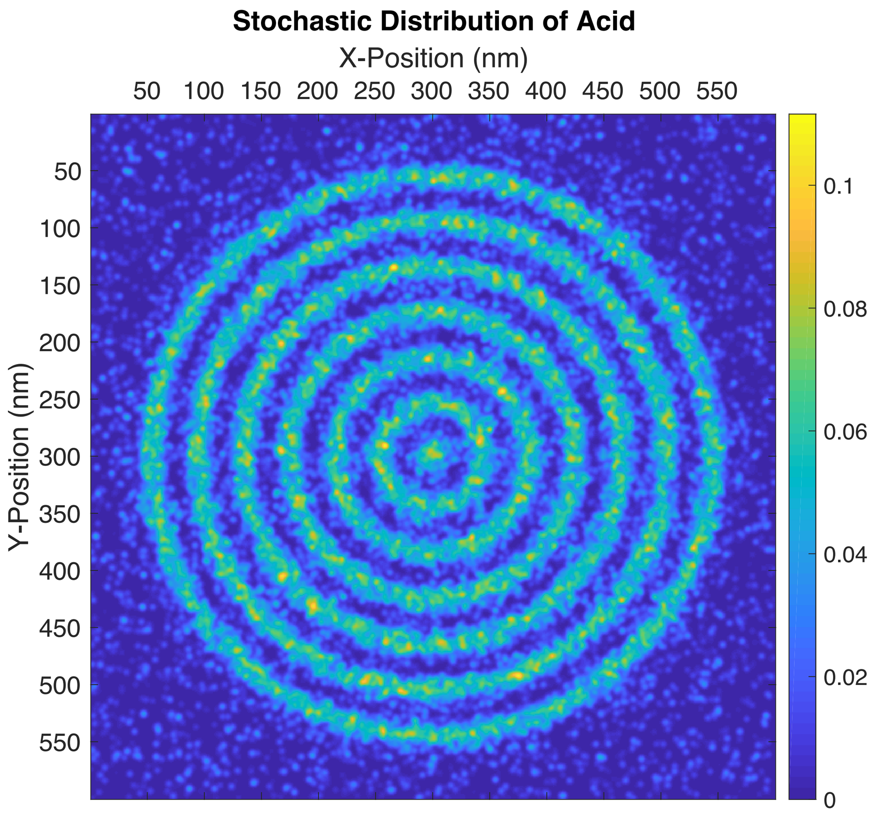
Stochastics of Acid Generation



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Basic Diffusion

- Fick's Law: $\frac{\partial\rho}{\partial t} - D\Delta\rho = 0$
- The solution can be written as the convolution of the initial distribution with the impulse response
  - $\Gamma(\vec{x},\vec{x}',t) = \frac{1}{(4\pi Dt)^{3/2}}\exp\left[-\frac{(\vec{x}-\vec{x}')^2}{4Dt}\right]$
  - $\rho(\vec{x},t) = \rho(\vec{x}',0) * \Gamma(\vec{x},\vec{x}',t)$
- Produces a gaussian sphere around initial distribution
  - Kernel smooths high frequency roughness
  - Wide gaussian in space is narrow in frequency
  - Fundamental to RLS Trade off: increasing diffusion decreases L but also R

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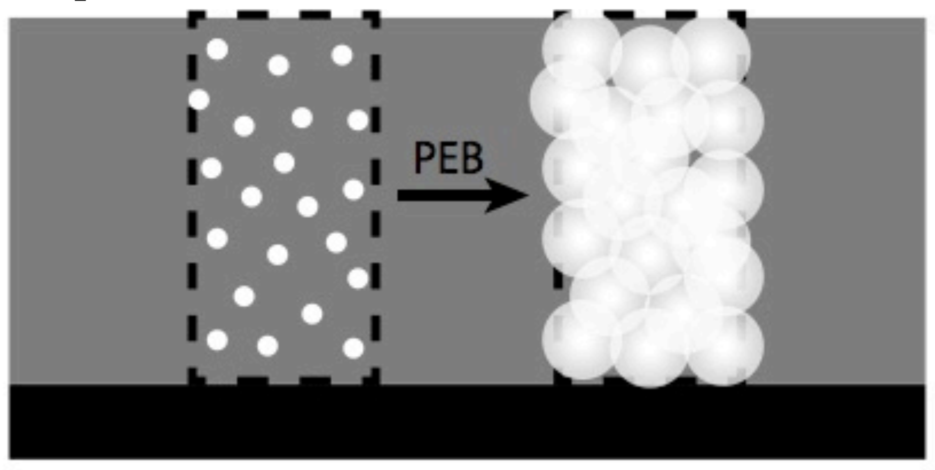
Current Stochastic Model

- Iterative Reaction-diffusion scheme
- Distribute molecules/ photons according to Poisson
- Diffuse acid and quencher
- React acid with protection sites
- React acid with quencher
- Repeat



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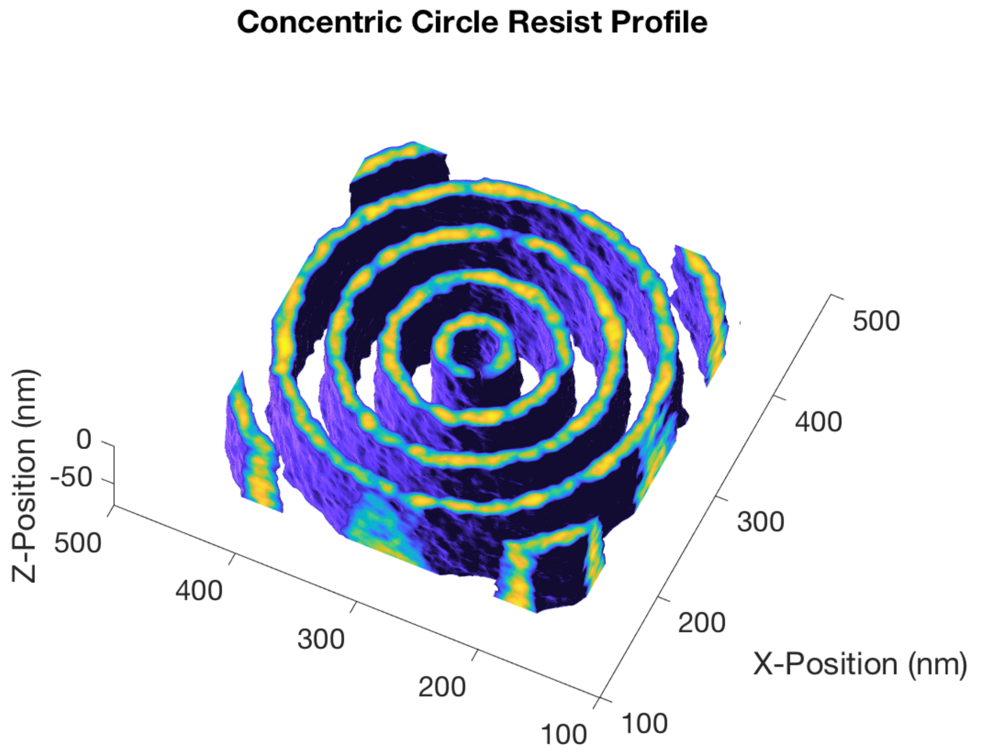
Current Stochastic Model



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Deprotection-Dependent Diffusion

- Current model predicts $\Delta x \propto \sqrt{\Delta t}$
- In DUV, a constant velocity diffusion front has been observed
- Perhaps due to deprotection-dependent diffusion constant
  - As resist deprotects, outgassing causes an increase in free volume while collapse causes a decrease
  - $\frac{\partial\rho}{\partial t} - \nabla\cdot(D(V_{Free})\nabla\rho) = 0$
- Changes resist performance near corners

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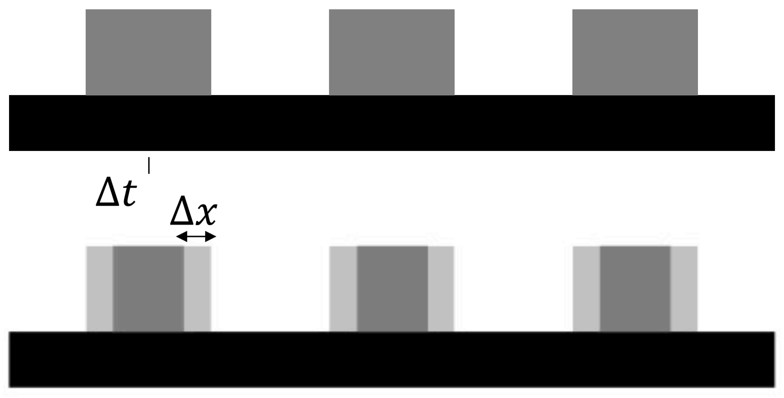
Linewidth vs Baketime

- Print a line/space pattern and bake for a short time
- Develop and measure linewidth
- Repeat for longer bake times with the same development conditions
- Observe relationship between Δx and Δt



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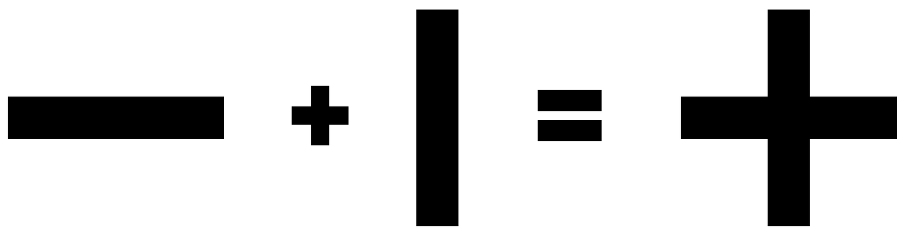
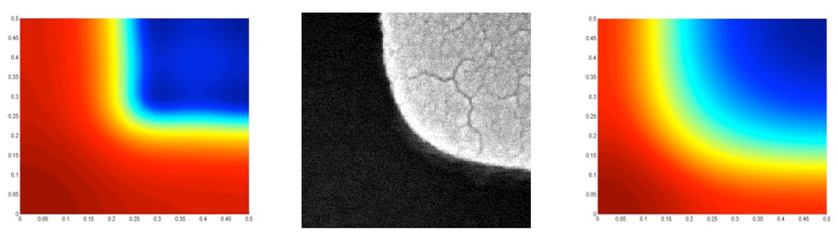
Double-Exposed Cross





Enhanced   Experiment   Reduced

-Yuan, SPIE 2003

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Near-term goals

- Perform Linewidth vs Baketime Experiment
- Perform Double Cross Exposure Experiment
- Model the results using our 3D stochastic model, solving spatially-dependent diffusion constant PDE if needed
- Perform similar experiments in metal-organic resists
- Rationalize findings and compare with our understanding of CAR used in DUVL

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Future Goals

- Use new technologies such as helium ion microscopy for minimally damaging resist metrology
- Explore using AFM to measure pre-development resist stochastics
- Explore the possibility of studying full-strength resist development in-situ via AFM
- Explore stochastics and modeling of metal-organic resists

Acknowledgment
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